Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE CRYSTALLINE ROCKS OF THE OAK HILL AREA NEAR SAN JOSÉ, CALIFORNIA

E. P. CAREY AND W. J. MILLER

CONTENTS

INTRODUCTION.
TOPOGRAPHY.
THE DIORITES.
    Occurrence and Relations.
    Petrographic Characters.
    Chemical Analysis.
THE GABBROS.
    Occurrence.
    Petrographic Characters.
    Relations.
    Chemical Analysis.
THE OLIVINE PYROXENITE.
    Occurrence.
    Petrographic Characters.
THE PERIDOTITE-SERPENTINE.
    Occurrence and Associations.
    Petrographic Characters.
    Genesis of Serpentine from Peridotite.
    Chromite.
    Cinnabar.
    Analysis.
SLICKENSIDED SERPENTINE.
MOTTLED SERPENTINE.
"SILICA CARBONATE SINTER."
    Petrographic Characters.
THE GLAUCOPHANE SCHISTS.
    1. Ordinary Typical Glaucophane Schist.
    2. Garnetiferous Schist.
    3. Acid or Quartz-bearing Schist.
    Suggestions as to Origin.
MAGMATIC DIFFERENTIATION.

INTRODUCTION

The Oak Hill area is situated about four miles south of the city of San José, in the Santa Clara Valley, California. On the north of this area is a quarry from which the city of San José obtained road material for a number of years. The road material consisted largely of diorite intruded into partially serpentinized peridotites and pyroxenites, with which they are very intimately associated.

The area mapped and studied in detail comprises nearly three square miles, namely the group of hills south of the Oak Hill Cemetery and west of the Monterey Road. This group of hills rising out of the Santa Clara Valley will be designated in this paper as the Oak Hill area, while the term "Quarry Hill" will be applied to the hill in which the quarry is situated.[1] The prevailing rock of the region is serpentine, which shows unmistakably its origin from peridotite. The transitions have been most carefully studied in and near the quarry. Not less interesting, however, are the pyroxenite and gabbro occurrences which are intimately associated, the pyroxenite showing every step in the transition into serpentine, on the one hand, and apparently into the different types of gabbro, on the other. Several diorite dikes occur cutting through the more basic rocks, and glaucophane schist has been found in a number of excellent exposures.

The region is further remarkable for the extent and variety of intrusives of more acid rocks, gabbroid and dioritic in character.

Sandstones and radiolarian jaspers make up a small part of the area and are the only rocks of sedimentary origin.

TOPOGRAPHY

The Oak Hill area comprises a group of well-rounded crests, part of an old erosion plain rising out of more recent valley alluvium which surrounds the hills on all sides. These hills really form an integral part of the Mount Hamilton Range, and are practically connected with this range by a low line of peridotite-serpentine hills, sometimes known as the Los Lagrimas Hills, which outcrop to the southeast of the Monterey Road.

Of the nine fairly well-defined crests of the area, the highest is 438.5 feet above the level of the valley. The trend of the crests is approximately northwest and southeast, which corresponds to the general strike of the Coast Ranges in this region.

---

[1] Work on the rocks of the Oak Hill area was carried on during the two years 1901 and 1902. The petrographic investigations were carried on at Stanford University under the direction of Dr. J. P. Smith.

The surface of the serpentinized area is hummocky and often almost destitute of soil, which character aids in determining the areal extent of the serpentine.

THE DIORITES

Occurrence and relations.—The Diorite occurs in dikes intrusive into the older pyroxenite—peridotite rocks and gabbros. The best exposure is to be found in the quarry. The dikes here constitute two sets: an older set of five nearly vertical dikes, averaging about three and a half feet in width and parallel with each other, intersected by another set of parallel dikes, averaging about four and a half feet in width and dipping toward the northwest.

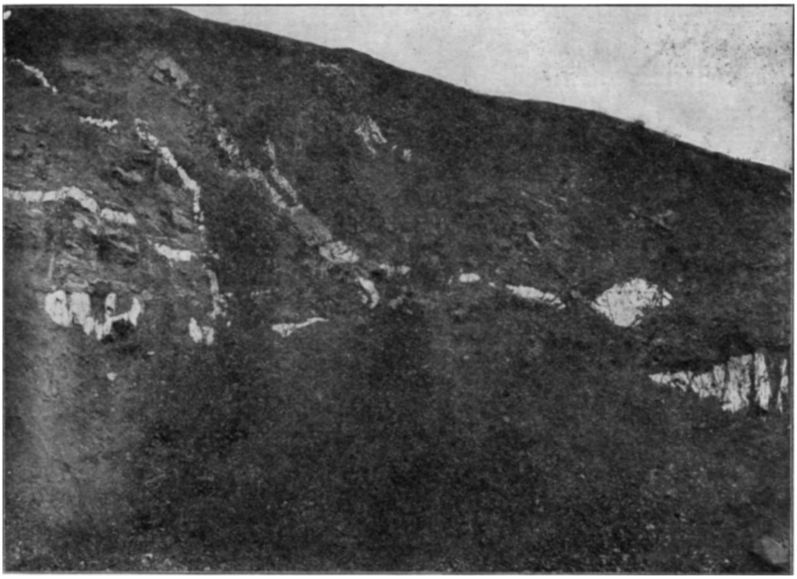

FIG. 1.—North face of Quarry Hill, showing diorite dikes in pyroxenite, gabbro, and serpentine.

The relations of these two intersecting sets of dikes are now, since the field-work was done, rather obscure, on account of a talus that is beginning to cover up some of the intersections; but some intersections are still apparent, as is evident from the photograph, and the relative age was plainly evident when the work of quarrying the diorite was in progress.

Both sets of dikes have been faulted after the intrusion, the fault zones being common to both sets of dikes. Three of these fault zones may be seen in the quarry in addition to minor displacements; but the displacement in no case exceeds a few feet. Pyroxenite, gabbro, and serpentine fill the space between the dikes in the quarry. In a cut near the east side of Quarry Hill a large diorite dike in pyroxenite shows spheroidal weathering, where the soft outer layers, which may be easily removed, grade into extremely hard spherical cores. Other fine-grained dioritic dikes may be seen intruded into norite in an open cut on the north side of the top of Quarry Hill. Other scattered outcrops of diorite were found on Quarry Hill and over the north part of Oak Hill area, but no exposures have been observed to the south of the area nor in the Los Lagrimas Hills to the southeast.

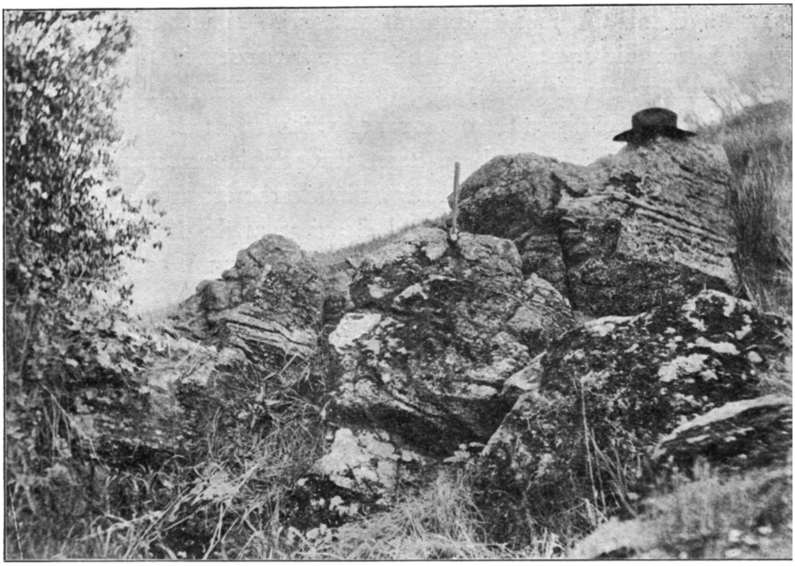

FIG. 2.—Banded structure in olivine gabbro—Quarry Hill—common also to pyroxenite and norite.

Petrographic characters.—The color of the hand specimen varies from a light to a dark gray, while the texture varies from very fine to rather coarse-grained, so that the commonest minerals, plagioclase and hornblende, may easily be seen with the naked eye. One of the most striking features of the coarser-grained specimens is the prominence of the hornblende crystals which make up one half of the rock. Because of slower cooling, the inner portions of the large dikes are more coarsely crystalline than the outer portions, while the narrow dikes and numerous branching tongues are fine-grained.

Upward of twenty thin sections were examined, and the chief constituents were found to be: plagioclase, hornblende, augite, biotite, and iron-oxide. Plagioclase, chiefly oligoclase and andesine, is, in all cases, the most abundant mineral. It usually occurs in large idiomorphic crystals, frequently twinned according to the albite law. The crystals are always weathered, sometimes almost beyond recognition, especially in the older set of dikes.

Hornblende, rather evenly scattered through the sections, is almost as important as plagioclase. It shows its characteristic pleochroism, and in many cases also its typical cleavage angle of about 124°. Sometimes the hornblende is concentrated into small green patches about the size of a pea.

Orthoclase is a minor constituent compared to plagioclase and usually occurs in irregular grains.

Augite is quite abundant in some specimens, while in others it is entirely absent. It usually appears in well-developed crystals showing a brown color, very slight pleochroism, and characteristic cleavage angles of 87°.

Biotite is a minor constituent, but often occurs in the typical brown patches with fine basal cleavage and strong pleochroism.

Iron oxide occurs as occasional opaque irregular grains in all of the sections examined.

A study of the diorites shows a considerable variation of these rocks among themselves. Some contain very little augite and feldspar while they are very rich in hornblende. Such rocks would readily suggest a similarity to the gabbros in basicity. Other diorites contain much less hornblende, but more feldspar and augite, and are the most acid rocks of the series.

Chemical analysis.—The following is a partial analysis of the typical Quarry Hill diorite furnished by the United States Geological Survey to Dr. J. C. Branner:

SiO_2	51.52
Al_2O_3	23.14
Fe_2O_3+FeO	6.17
TiO_2	0.33
CaO	9.58
MgO	1.64
P_2O_5	trace
Total	92.38

THE GABBROS

Occurrence.—Among the igneous rocks of the Oak Hill area the gabbros are smallest in amount. They occur on Quarry Hill and seem to grade over, on the one hand, into the basic pyroxenite-peridotites and, on the other, into hypersthene gabbro or norite. Among themselves the gabbros are very variable in mineral composition. They range from a typical olivine gabbro to a hypersthene gabbro. There is no evidence of intrusion. On the other hand, the field relations together with the microscopic evidence demonstrate a transition into serpentine. A tunnel into the base of Quarry Hill on the north side penetrates the norite for about seventy-five feet. An open cut on top of the hill immediately above this tunnel shows exposures of the same norite. In the field a distinct gneissic structure is noticeable, which in this phase of the rock is scarcely evident in the hand specimen. Outcrops of the other gabbro are irregularly scattered over Quarry Hill, and none are found over the other parts of the area studied.

Petrographic characters.—The gabbro and norite are granitic in texture and of dark-gray color. The typical gabbro is usually medium grained, while the norite is slightly finer-grained. In the hand specimen the plagioclase, olivine and diallage of the gabbro are plainly visible to the naked eye. The plagioclases with their shiny surfaces and the diallage crystals with their greenish shiny faces appear to be unusually fresh. In the norite the plagioclase and the hypersthene are likewise visible to the naked eye. Here the plagioclase appears slightly more weathered than that of the gabbro. The hypersthene occurs in numerous brown crystals evenly scattered throughout the mass.

In marked contrast to the diorites, the minerals in many of these gabbro-norites are clear and fresh. The list of minerals in this series of rocks includes the following: plagioclase, hypersthene, diallage, enstatite, hornblende, olivine, augite, and iron-oxide. Sometimes all of these may be seen in a single section.

Plagioclase, chiefly labradorite, is the most constant of the minerals present. It occurs in clear glassy plates the crystals being usually well-defined. Twinning according to both the albite and carlsbad laws is common. Sometimes pericline twinning was observed. Olivine and hypersthene are occasional inclusions.

Hypersthene is the second most abundant mineral in the typical norite. Very little, or sometimes none, is present in the gabbro. The hypersthene usually appears as allotriomorphic crystals. The pleochroism from reddish-brown to greenish-yellow to green is very distinct. The hypersthene seems generally rather fresh but sometimes it is weathered to a green serpentinous mineral.

Diallage is the next most common mineral in the typical gabbro, but is less abundant in the norite. It appears as large irregular crystals, often blurred by weathering. In ordinary light it varies from nearly colorless to a light green. The fine striations so characteristic of diallage are well developed. The crystals exhibit a metallic sheen and show no pleochroism. In a few instances twinning was noticed. Plagioclase is often included in the diallage, and very often the diallage has grown partially around the plagioclase, thus showing it to be later in formation.

Enstatite is abundant in some of the gabbros. It always occurs without regular crystal boundaries. The highly characteristic columnar structure and the parallel extinction are well shown.

Hornblende is usually absent from the typical gabbro; it is present to only a small extent in the norite; but in sections from a few outcrops it is so predominant that the rocks may readily be called hornblende-gabbro. In the latter rocks much of the hornblende is badly weathered and is altered to cholorite in green patches. The characteristic cleavage lines making angles of about 124° are very distinct in the primary hornblende. It exhibits a pleochroism from a green to a light yellow. Examples of twinning are also quite common.

Common augite occurs in considerable quantity in the norite, but scarcely any is present in the gabbro. The individuals are allotriomorphic and very irregular in shape, but show the usual cleavage angles of 87°. The pleochroism of the augite is from a colorless to a light brown. It may often be seen perfectly twinned. Some inclusions of olivine were noticed.

Olivine is a constant constituent of all the gabbros. In ordinary light it is colorless, while in polarized light it exhibits the characteristic high relief and strong double refraction. The crystals are usually rounded, but are generally much weathered and blurred. It is often serpentinized along irregular cracks that ramify through the crystals.

Magnetite is found in small opaque patches scattered through all the sections of gabbro and of norite.

Relations of the gabbros.—From a study of the field relations and the examination of a number of thin sections it is evident that the different variations of gabbro are merely local. Some of the gabbros have much olivine—olivine gabbro; some have much hornblende—hornblende gabbro; many of the gabbros have abundant hypersthene—hypersthene gabbro or norite; many have a predominance of diallage—normal gabbro.

The typical norite from the cut at the top of Quarry Hill contains much hypersthene, together with some hornblende and augite, while it contains little olivine and diallage. On the other hand, the typical gabbro contains much diallage, but practically no hypersthene, hornblende, nor common augite. Sections have been examined which show almost perfect gradations between these various kinds of gabbro, thus strongly suggesting that they are phases in the differentiation of the same magma.

Those gabbros which are rich in diallage and poor in hypersthene, hornblende, and augite most nearly approach the pyroxenites, next to be described, in constitution. Those which are rich in hypersthene, hornblende, and augite, but poor in diallage, most nearly approach the diorites. Thus the gabbros which undoubtedly represent the most acid end of the interesting basic series of pyroxenites, peridotites, and resulting serpentines may also be a connecting link between these and the more acid diorites. All the above gradations may be observed within a radius of seventy-five yards of Quarry Hill.

Chemical analysis.—Following is a partial analysis of the olivine gabbro furnished to Dr. J. C. Branner by the United States Geological Survey:

SiO_2	48.11
Al_2O_3	14.67
Fe_2O_3+FeO	6.45
TiO_2	0.15
CaO	17.55
MgO	11.19
P_2O_5	none
Total	98.12

THE OLIVINE PYROXENITE

Occurrence.—This rock occurs mainly in and about the quarry, and is made up essentially of olivine and diallage with some magnetite. The percentage of diallage varies from a few scattered crystals, as in the massive varieties of serpentine, to a rock made up almost entirely of diallage. The olivine is never wholly free from the process of serpentinization, except in the gabbro phase of the rock, and usually no feldspar is present. It is evidently a phase of the serpentine, the difference being chiefly in the relative proportion of the olivine and diallage.

Petrographic characters.—A gneissic structure common to the gabbros is also, in this rock, very perfectly developed, and is accentuated at the surface by weathering. The diallage crystals are generally nearly a centimeter in length and quite uniform in size. Their cleavage surfaces are brassy in appearance, in some cases quite dark. When near the serpentine phase the whole rock becomes dark, resembling the massive serpentine. On the southeast side of the quarry entrance the rock is practically a diallagite, of a greenish-yellow color. On the south face of the quarry this rock contains feldspar and fresh olivine, thus passing into the gabbro phase. The optical properties of the diallage and olivine are the same as in the gabbro.

THE PERIDOTITE-SERPENTINE

Occurrence and associations.—Serpentine forms the greater part of the Oak Hill area and can be traced almost continuously severa miles along the Los Lagrimas Hills southeast to the Mount Hamilton Range. It is about eleven miles from the serpentine of the New Almaden region described by Becker.[1]

In most respects it is similar to the serpentine of the San Francisco Peninsula, Angel Island, Crystal Springs Lake, and numerous other occurrences in the Coast Ranges; and it is probably identical in age with them. It is associated with radiolarian cherts and sandstones which belong to the formation described by Professor Lawson[2] as San Franciscan, and by Dr. H. W. Fairbanks[3] as Golden Gate.

The serpentine mass here represents an intrusion in the nature of a boss or very large dike. The outcrop reaches a width of one and a half miles. The extent below the surface cannot be determined because in most places it is buried beneath the alluvium which covers the valley floor.

The prevalence of schist about the periphery of the serpentine, together with the fact that the jaspers, where they occur, are frequently contorted and otherwise altered, would suggest that serpentine was capable of affecting to a considerable degree the rocks into which it was intruded; yet this evidence is not conclusive.

Petrographic characters.—The serpentine varies greatly in character. It typically consists of crystals of diallage imbedded in a groundmass varying in color from a light to a dark green, consisting chiefly of the mineral serpentine, in which are numerous grains of magnetite. Enstatite and iron-pyrites are found very sparingly, while a large portion of the slides show residual grains of olivine. The process of serpentinization is also observed in some of the imbedded diallage crystals working in along the cleavage planes from the outside to the center, although this mineral is usually fresh.

This massive phase of the peridotite-serpentine varies in composition from a rock, in which the glistening face of a diallage crystal may be seen here and there imbedded in serpentine, to one made up essentially of diallage, the latter presenting an uneven fracture, while the former is a compact rock with a conchoidal fracture.

---

[1] *Geology of the Quicksilver Deposits of the Pacific Slope,* Monograph XIII, U. S. Geological Survey.

[2] *Geology of the San Francisco Peninsula,* Fifteenth Annual Report, U. S. Geological Survey.

[3] "The Stratigraphy of the California Coast Ranges," *Journal of Geology,* Vol. III (1895), pp. 415-33.

The mesh structure is common, especially in the compact conchoidal variety, while grains of olivine and minute crystals of magnetite are disseminated throughout the whole mass. The minute crystals of magnetite may be detected in the groundmass by the aid of a pocket lens, and are so numerous that the fine powder of the crushed serpentine will immediately jump to a magnet. These magnetite crystals are chiefly concentrated along the lines common to contiguous meshes, but are at times also found along with serpentine, making up dark anastomosing veins, attaining in some instances half an inch or more in width.

Genesis of serpentine from peridotite.—The structure and mineralogical composition of this serpentine then clearly indicate that it was derived from a basic rock in which olivine was the predominating mineral together with diallage and magnetite. The peridotite from which the serpentine was derived is not found in a fresh condition. It is interesting, however, to note that in the phases of the rock in which diallage predominates we do have a comparatively fresh rock, which fact confirms the igneous origin of the serpentine.

Chromite.—Several somewhat irregular pockets of chromite in peridotite-serpentine occur in the Los Lagrimas Hills, never exceeding a few feet in extent. The relative hardness of the ore in some cases caused it to stand up above the surrounding surface. On this account it attracted attention, and formerly on the Swickard ranch near the Coyote Creek, these occurrences were mined, and the product shipped east. So intimately associated is the serpentine with the chromite that it is difficult to secure from these prospect holes a hand specimen of the ore that does not contain serpentine. It would seem as if the chromite is a product of differentiation from the serpentine.

Cinnabar.—The San Juan cinnabar mine occurs on the Oak Hill area. Here the ore occurs along joint planes and zones of faulting, the impregnations extending some distance from the walls into the serpentine and its alteration products. Extensive mining is not now carried on in this region, though operations are now being conducted in a small way.

At the Silver Creek mine, four miles south of Evergreen, in apparently this same range of serpentine, the conditions are very similar. It would appear that formerly comparatively extensive mining operations were carried on at both these places.

Analysis of serpentine.—The analysis of this serpentine was furnished by the United States Geological Survey at the request of Dr. Branner. The other analyses of Coast Range serpentines are given for comparison.

	I	II	III
SiO_2	37·71	39·60	42.06
Cr_2O_3	.....	0.20	.....
Al_2O_3	1.81	1.94	2.72
Fe_2O_3	10.47	.....	.....
FeO	.....	8.45	2.88
MnO	.....	.....	.....
MgO	35·60	36.90	39·53
Na_2O	(not	determined)	
TiO_2	0.09	.....	.....
H_2O	(not det.)	12.91	12.04
Total	85·95	100.00	99·23

I. Massive conchoidal serpentine of the Oak Hill area, by United States Geological Survey for Dr. Branner.

II. Serpentine from Presidio, San Francisco; analyst, Dr. Easter. *Pacific Railroad Reports,* Vol. VI [1855]. (Pt. 2, p. 11.)

III. Serpentine hard sound nodule in crushed matrix; analyst, Dr. F. L. Ransome. ("The Geology of Angel Island," *Bulletin of the Department of Geology of the University of California,* p. 231.)

Analysis No. 1 (United States Geological Survey) confirms the conclusions reached above. The original rock was evidently ultrabasic. The large percentage of iron is doubtless accounted for by the presence of the mineral magnetite, while the mineral serpentine makes up a large part of the remainder of the rock. The proportion of silica to magnesium also approaches that ratio in the pure mineral serpentine, in which 40.42 per cent. of magnesium corresponds to 41.52 per cent. of silica. The evidence is clear that the serpentine is an altered igneous rock. On some of the slopes of the Oak Hill area, where both sandstone and serpentine are exposed, a mechanical mixture of serpentine and sand has been formed.

SLICKENSIDED SERPENTINE

This aspect of the serpentine in most respects closely corresponds to that described by Dr. Palache.[1] The rock is varied in character, being found from a gray to a light green shade, and is quite soft. The plane slickensided faces, often greasy and striated, predominate over curved faces, so that in many places it has a foliated or schistose structure. This phase occurs in rather extensive zones which appear to be fault zones, and also along joint planes in the peridotite-serpentine, which are frequently planes of movement. In some cases the slickensiding has extended out from the joint planes, involving the peridotite-serpentine until it remains as a core in the center of the slickensided variety.

While at the Potrero the massive facies is very subordinate in amount, in the Los Lagrimas Hills and the Oak Hill area the reverse is the case, and the bowlders are represented in a few places in the beginning stages of formation.

MOTTLED SERPENTINE

Associated with the massive green serpentine in and about the quarry occurs a light green facies in which roundish light colored areas are found in the green or grayish-green variety making up about half the rock, and giving to it a very striking and mottled appearance. The light spots vary in size from points barely visible to the size of a hen's egg or even larger. The microscope shows that the mesh structure is present in the least decomposed parts of the white areas and is continuous from the contiguous green part, in some cases gradually disappearing as the center of the white area is approached. Small magnetite crystals are also present, though not so numerous, and have a similar distribution. Often small cores of the greenish serpentine occur within the white areas, frequently near the center.

Qualitative analysis demonstrated abundant silica and magnesium, indicating that it is essentially magnesium silicate, and that it is derived from the mineral serpentine by secondary changes, possibly accompanied by the leaching out of iron. The frequent occurrence of this white material in veins, and the fact that the surface of the greenish variety weathers to this same product, would tend to confirm this view.

---

[1] "The Lherzolite Serpentine and Associated Rocks ot the Potrero," *S. F. Bulletin of the Department of Geology of the University of California.*

These patches disintegrate on exposure more readily than the massive green variety, and in some instances accentuate the very irregular and fantastic forms that result from surface weathering.

This change of the mineral serpentine to magnesium silicate, which is common in serpentine areas, seems to be an intermediate one, and frequently precedes the release and subsequent deposition of silica and the taking-up of carbon dioxide, thus forming a rock made up of carbonates and various forms of silica, together with compounds of iron, etc. Such a rock occurs quite abundantly in the vicinity of the Oak Hill area, and will now be described.

"SILICA CARBONATE SINTER"

Its occurrence in the serpentine appears to be somewhat sporadic, and there is no fixed evidence to indicate that it is either an inclusion, a dike or a vein. On the other hand, it seems to bear relationships with the serpentine with which it is found and into which it grades. At times it occurs in the form of a dike or vein, but may be irregular in outline. The alteration in some cases is so complete that the rock has many characteristics of a vein.

Petrographic characters.—Professor Lawson described what is evidently this same rock under the tentative name "Silica-Carbonate Sinter,"[1] and his description applies so well that I quote it here:

> Petrographically the rock is an exceedingly irregular and intricate mixture of silica in the form of opal and chalcedony and carbonates of lime, magnesia, and iron. The silica is present usually in the form of a mesh-work of veinules, which, however, do not seem to fill fissures in the carbonate, but to be of contemporaneous formation with it. These veinules anastomose, but do not commonly intersect, and they vary greatly in their thickness. In weathering, the carbonate of iron yields an abundant ochre, the other carbonates are leached out, and the silica remains as a honeycombed mass, giving rise to exceedingly irregular and fantastic, pitted and cavernous forms, which project ruggedly above the general surface. It is difficult to get a fresh mass of the rock quite free from the yellow ochre. In the least decomposed specimens the carbonates are seen to have the crystalline texture of marble with a yellowish color. Occasionly there is a bright green strain apparent in the rock which may be a silicate of iron.

---

[1] "Geology of the San Francisco Peninsula," *Fifteenth Annual Report of the U. S. Geological Survey*, p. 435.

In a recent letter to Mr. Carey referring to the genesis of his rock, Professor Lawson says:

> I have seen a good deal of that so-called "Silica-Carbonate Sinter," since I wrote my paper on the geology of the San Francisco Peninsula, and have established to my own satisfaction that the rock in question is an alteration product of serpentine, and that the cases where it appeared to be interbedded must be cases of intrusive sills. It is thus a chemical rock, but due to alteration, and I think the term "Sinter" therefore a misnomer and will not myself use it.

This rock, then, is the final or end product of an interesting chemical transformation in connection with serpentine. It possesses the composition and properties that would be predicted for it apart from any evidence. Remnants of serpentine have been found in this rock, and all stages in the transformation observed.

THE GLAUCOPHANE SCHISTS

The glaucophane schists of the Oak Hill area and vicinity occur as distinct outcrops on the southern and eastern portion of the hills, in general near the periphery of the serpentine. They present nearly as many facies as there are occurrences. It is difficult to observe contact phenomena, but in one instance at least it appears that the glaucophane schist is completely surrounded by serpentine; two other outcrops are closely associated with, if not actually in contact with, jasper; while still in another, glaucophane schist is in the immediate vicinity of sandstone and appears to grade into it.

The glaucophane schists of the Oak Hill area may be described under three heads.

1. *The ordinary typical glaucophane schist.*—In this facies the schistosity is eminently developed, and the schist can be readily split into large thin pieces. It is uniformly bluish in color, and contains flakes of mica which are plainly visible to the naked eye.

The microscope shows this rock to be made up essentially of glaucophane, with some mica, lawsonite, and titanite. The glaucophane prisms show the well-established glaucophane orientation. In the glaucophane the $\mathfrak{a}$ ray is pale greenish-yellow; the $\mathfrak{b}$ ray is purplish-violet parallel to the long diagonal of the basal sections; the ray is sky-blue, and the inclination of $\mathfrak{c}$ to C' is about 8°. The absorption is $\mathfrak{b} < \mathfrak{c} > \mathfrak{a}$. In addition to the prism, clinopinacoidal faces were observed on many crystals. The cleavage parallel to the prism is perfect with angles of about 124.°

The lawsonite crystals are comparatively fresh and occur in considerable quantity. A good outcrop of this rock is found near the present workings of the San Juan mine.

2. *The garnetiferous schist.*—The chief difference between this and the typical schist is the relatively smaller amount of glaucophane, the development of numerous garnets, and a somewhat less marked schistosity, the rock being more massive. The garnets, which are irregularly distributed throughout the rock, average about one millimeter in diameter, and can often be detected with the unaided eye. The mica flakes, which are also unevenly distributed, are small, but very numerous. It has been mentioned as eclogite by Mr. R. S. Holway.[1]

The microscope reveals the presence of much garnet and chlorite, some lawsonite, actinolite, glaucophane, and usually also white mica. The garnets usually appear in well-defined crystals, showing high index and high relief. The individuals are nearly always strongly fractured and the cracks filled with green chlorite. In ordinary light the garnets are light reddish-brown in color. The lawsonite is scarce in this rock, appearing as small weathered patches. The green chlorite occurs in abundance in rough, irregularly shaped patches. The glaucophane is not abundant; it occurs as small blue prismatic crystals with properties as described in the typical schist. The mica, like a garnet, is unevenly distributed through the rock. It is of a slightly brownish tint and is probably paragonite.

3. *The acid or quartz-bearing schist.*—The most highly acid exposure of this type of schist was found in close proximity to highly altered banded jaspers in which the typical features, including the banded structure, had disappeared, and the rock was identified only by the presence of radiolaria as shown by the microscope.

The schist is massive and made up almost entirely of silica in indistinct bands of variable thickness, with a little mica on the surfaces. The microscope, however, shows in the slide here and there a deep blue prism of glaucophane imbedded in the silica, and innumerable minute pink dodecahedral garnets.

---

[1] "Eclogites in California," *Journal of Geology*, Vol. XII, No. 4. (1904), p. 354.

In other instances the rock appears to be a mica schist, with free quartz intercolated irregularly between the planes of schistosity. The bands are crumpled, and the crystals of glaucophane are broken, distorted, and frequently healed with quartz.

Suggestions as to origin.—The close association of the glaucophanes with the jaspers and sandstones would suggest a genetic relationship. According to F. L. Ransome,[1] the glaucophane schists of Angel Island, San Francisco Bay, are the result of the metamorphism of the radiolarian cherts as well as the feldspathic sandstones. The schist there consists of quartz, albite, glaucophane, biotite, etc. Some of the Oak Hill rocks are very similar to those in composition. This close association of the glaucophane schists and jaspers has been commonly observed in the Coast Ranges of California.

Some of the Oak Hill glaucophane schist is rich in argillaceous matter. Near the border of this schist fairly large flakes of a light brown mica have been developed, while nearer the center of the mass little or no mica appears.

Although no positive general statement can be made with reference to the origin of the glaucophane schist, nevertheless it is certain that at least in some cases they are the products of the metamorphism of sediments. This is undoubtedly true of the more siliceous facies, while the more basic facies may have resulted from the alteration of tuffs of ingneous rocks. Ransome ascribed their origin to contact metamorphism, while Nutter and Barber[2] thought that dynamic metamorphism alone could account for the origin of the greater schist masses of the Coast Ranges. It would appear that further investigation along the line of mineralizing effects of solutions in metamorphic zones is necessary to explain the genesis of glaucophane and associated minerals.

MAGMATIC DIFFERENTIATION

In the foregoing description of the gabbros, pyroxenites, and serpentines with their products, it has been pointed out that, while all the rock types are very distinctly shown, nevertheless the transitions are so evident that it has been found artificial to make separate classes. The field indications show conclusively that the pyroxenite grades into the typical gabbro on the one hand, and into the olivine-pyroxenite on the other. Further, this olivine-pyroxenite, which in one phase is practically a diallagite, in other phases goes by insensible gradations into peridotite-serpentine; that is, the phase of the pyroxenite, richest in olivine (peridotite) has become serpentinized and gives us peridotite-serpentine and serpentine.

---

[1] *Bulletin of the Department of Geology of the University of California*, 1894, pp. 193–240.

[2] *Journal of Geology*, Vol. X, No. 7 (1902), p. 742.

This serpentine, it has been suggested, gives up its iron, yielding veins of magnesium-silicate, which in turn liberates silica, takes up carbon-dioxide, forming magnesium-carbonate. Thus we find over the area the free oxides of iron veins and patches of magnesium-silicate, and, where conditions favor the taking-up of carbon-dioxide, magnesium-carbonate. When the carbonates, silicates, free silica, and iron-oxides are all mixed in one complex rock, we get a product that has been described under the name "silica carbonate sinter."

The hypersthene gabbro in the field has not been observed in direct connection with the other rocks of the gabbro-pyroxenite-serpentine series; it, however, shows no evidence of intrusion. It is in very close proximity to the typical gabbro, and is found nowhere else over the area. Its mineralogical variation, moreover, would lead to the conclusion that it is but a phase of the ordinary typical gabbro.

Olivine, it has been noted, is common to all this rock series, increasing in freshness from the serpentine to the hypersthene-gabbro. These rocks also have a banded structure in common. The mineral diallage is also common to all the rocks of the series. Its ratio to olivine accounts for the variations from diallagite, olivine-pyroxenite, peridotite-serpentine to serpentine. In acidity we have an increase from 37.71 per cent. of silica in the serpentine to 48.11 per cent. in the gabbro.

The authors, in conclusion, wish to express their thanks to Dr. J. P. Smith, for his constant aid and advice; to Dr. J. C. Branner, for the chemical analyses secured from the United States Geological Survey. Mr. F. H. Tibbetts, a former student of Mr. Carey's, aided materially in the construction of the topographic map.